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A Social Utility-Based Dissemination Scheme for Emergency Warning Messages in Vehicular Social Networks

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In recent years, many schemes have been proposed to disseminate Emergency Warning Messages (EWMs) in VANETs. However, various problems such as broadcast storm, hidden terminal and connectivity issues still persist to reduce the efficacy of these systems. In this paper, we propose a novel Social Utility-based Dissemination Scheme (SUDS) for Emergency Warning Messages in Vehicular Social Networks (VSNs). We utilize social properties of nodes such as centrality, interests and friendships to mitigate broadcast storm and hidden terminal problems. Furthermore, we employ the hybrid architecture of VSNs to solve connectivity and contact duration-related issues in sparse and high mobility environments. For this purpose, we devise a dual-strategy-based mechanism, where vehicles communicate with each other in a distributed or centralized manner according to the required situation. In order to evaluate the performance of proposed scheme, we have conducted extensive experiments for a highway scenario under varying vehicular density, vehicular speed and distance, in comparison with the state-of-the-art dissemination schemes. Simulation results have demonstrated the superiority of SUDS over the compared protocols in terms of delivery ratio, transmission delay and total number of transmissions. We have also demonstrated the positive effects of hybrid architecture of VSNs on various network parameters.

Keywords: vehicular social networks; emergency warning messages; social relationships; collision avoidance system

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1. INTRODUCTION

Vehicular communication technology has seen a tremendous growth in the past two decades to ensure safety and comfort of users through various services and applications. Among these applications, safety services hold the highest priority, as a massive number of human lives can be saved if alerted in advance about a mishap. Studies have shown that the number of vehicles per accident is much higher when a wireless collision avoidance system is not used [1]. In order to provide such safety services, many works have been proposed especially for Vehicular Ad hoc Networks (VANETs). The main objective of these services is to issue Emergency Warning Messages (EWMs) to the drivers that are moving towards a danger zone in both highway and urban scenarios [2, 3]. Therefore, reliable dissemination of EWMs is of utmost importance and requires efficient transmission protocols. However, usually EWMs have to be transmitted to regions far away from the communication range of the source vehicle. Therefore, multi-hop broadcast transmission techniques are adopted. The issue with multi-hop schemes is that too many messages may be generated leading to the broadcast storm problem, where broadcast messages circulate in the entire network. This eventually leads to crash the network down due to severe network congestion [4]. Moreover, strict standards of packet transmission for safety messages in Dedicated Short Range Communication (DSRC) lead to hidden node/terminal collision problem, where a node may be present physically but is not visible on the communication spectrum [5]. To avoid this issue, redundant re-transmissions are required, which deteriorates the performance of the network. Furthermore, VANETs-based techniques are prone to connectivity issues due to very high mobility and low density of vehicles, especially in highway scenarios. For instance, the minimal contact duration for vehicles with 200 m of communication range at 50 km/h is only 15 s [6]. However, the speed of vehicles is much higher on highways, with an average of at least 80 km/h or higher, which reduces the contact duration significantly.

In order to solve the aforementioned problems, new paradigms have been introduced in communication network technology. For example, Socially Aware Networking (SAN) has been introduced where social properties of nodes are explored for data forwarding and routing purposes [7]. Furthermore, social metrics-based data dissemination mechanisms in SAN and MSNs, such as [8, 9], respectively, have proven its importance to achieve higher delivery ratio and reduced overhead. Similarly, cloud-assisted vehicular systems can gather information such as vehicles' mobility patterns and location via smart terminals to make context-aware decisions [10]. Such concepts have led to the development of Vehicular Social Networks (VSNs) where various social properties such as centrality, community, similarity, mobility and interests are utilized to facilitate communication on the road. Recently we investigated various application scenarios for VSNs such as traffic anomaly detection in smart cities using trajectory data analysis [11]. In this context, VSNs offer new opportunities for researchers to mitigate problems like broadcast storm, hidden node and connectivity issues. Although many applications and infotainment-based designs for VSNs have been proposed by researchers, they still lack a standardized framework and architecture [12–14].

As social connections are rather stable and resilient to connectivity issues of highly mobile nodes, VSNs offer an opportunity to explore robust and efficient mechanisms for dissemination of EWMs. However, to the best of our knowledge, broadcast strategies for EWMs are yet to be explored in VSNs. These motivations have led us to explore Vehicular Social Networks for the dissemination of EWMs in order to tackle the aforementioned problems. In this paper, we propose a novel Social Utility-based Dissemination Scheme (SUDS) for EWMs in VSNs to ensure the safety of the users in emergency situations. The main contribution of this paper is threefold:

- First, we solve the network congestion issues like broadcast storm problem and hidden node collision, by exploiting the social properties of nodes such as degree and betweenness centralities, friendships and interest-based groups. We derive social utility functions for nodes taking into account the high mobility of the nodes. The social utility-based broadcaster-selection mechanism reduces the number of re-broadcasts and hence avoids the aforementioned problems.
- Second, we address the reliability of message dissemination and connectivity issues, by exploring rather stable social connections of the nodes. For this purpose, we devise a dual-strategy-based broadcast mechanism for EWMs using Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication. In very sparse conditions, the V2I communication negates the disconnection problem. On the other hand, if access to infrastructure is not available, then V2V mode is enabled for distributed communication.
- Finally, we develop a framework and design algorithms to carry out broadcasting of emergency warning messages under a VSN scenario, which is first of its kind at the time of submission, to the best of our knowledge.

The rest of the paper is organized as follows: Section 2 gives an overview of the most recent related and important works; in Section 3, we explain the architecture of our proposed scheme; Section 4 describes the working of SUDS; Section 5 is about simulation and performance evaluation in comparison with start-of-the-art protocols; finally Section 6 concludes the paper with some future directions.

2. RELATED WORKS

To mitigate broadcast storm problem, extensive work has been proposed in the literature over the last two decades [2, 3, 15]. The main goal of such mechanisms is to reduce the number of re-broadcasts by a variety of next-hop selection methods. We can broadly divide these methods into two categories: The conventional VANET-based mechanisms where various methods like time slot allocation, distance and location-based schemes, probabilistic approaches, etc. are adopted to select next forwarder. For instance, DV-Cast [16] uses slotted 1-persistence algorithm to tackle broadcast storm problem while it also incorporates the store-carry-and-forward method for dissemination in disconnected networks. It employs a distributed dissemination technique by detecting the network connectivity and then employs different mechanisms for disconnected, sparsely connected and fully connected networks. However, DV-Cast suffers from synchronized packet transmission because it uses timer-based technique. To overcome such problems Schwartz *et al.* [17] proposed a scalable dissemination protocol (AMD) for highway and urban scenarios. They used suppression-based time slot allocation to select next forwarder and store-carry-and-forward-based multi-directional dissemination scheme. In [18], authors propose an opportunistic dissemination mechanism where the relay node uses long-range ACK message to reduce redundant messages. In [19], a trinary partitioning mechanism is introduced to divide the communication range into small sectors. Then the farthest vehicle in the farthest sector is selected to forward the emergency warning message so that speedy dissemination is achieved by reducing the hop count. Chang *et al.* [20] proposed an adaptive dissemination scheme, where the broadcaster range is varied based on gathered traffic information, such as vehicular density, speed, communication range and area of city or suburbs. After analysis, the gathered information is shared with neighbor vehicles to alert them about the situation and hence reducing the message overhead. However, these methods are restricted to purely VANET-based environments where connectivity at higher speeds is a big issue. Moreover, with the advent of social networks, new paradigms such as VSNs have emerged where these protocols may not be applicable due to its completely different nature and architecture.

The second category is based on social network analysis and context-aware mechanisms. Daly *et al.* [21] proposed a social metrics-based scheme (SimBetTS), where social properties such as similarity, betweenness centrality and Tie-strength were used to derive a utility function that determined the importance of a node in the network for dissemination purpose. Xia *et al.* [22] proposed a set of interest-based forwarding schemes incorporating swarm intelligence. They implemented the idea of food forging process of bees to detect different variables in the environment. By dividing nodes into communities based on interests, they showed that forwarding of messages can be enhanced significantly, when sociality and tie strength among nodes is taken into account. Liang *et al.* [23] investigated synchronization problems in heterogenous complex networks by finding equivalent networks that are composed of simpler networks with lower dimensions. In [24], a node cooperation-based strategy for broadcasting of messages to mitigate the mobility and connectivity issues in vehicular networks is proposed. In this method, neighbor nodes re-broadcast the message. However, due to channel errors and network collision, the performance of the cooperative nodes degrades. Hu *et al.* [25] proposed a social-based multicast scheme for content dissemination in distributed mobile networks. In their scheme, they form ad hoc networks of mobile stations seeking the same content, who may multicast the content to their social contacts who seek it. They introduced geographical social strength to describe the social relationship between nodes. Kong *et al.* [26] proposed a crowdsourcing technique, where information about long-term anomalous traffic regions is mined. This traffic information is then used for future traffic planning to avoid any kind of mishap. In [27], a cooperative quality-aware service access system has been proposed for Social Internet of Vehicles using social interactions among vehicles.

In [28], Qin *et al.* demonstrated that vehicles exhibit dynamic sociality having a strong correlation with time. They proposed a Markov chain-based heuristic algorithm to select the most central vehicle for advertisement in vehicular networks. Cunha *et al.* [29] explored social metrics like clusters and degree centrality for dissemination in VANETs as well. However, both these systems take only distributed architecture of VANETs, unlike VSNs where nodes can make use of hybrid architecture. In [30], the authors have demonstrated that the output of a leader can be tracked down by follower's output and hence discrete-time multi-agent systems achieve leader-following consensus. Ning *et al.* [31] proposed a group formation framework for Narrowband Internet of Things to ensure connectivity and high link capacity, using social aware D2D relay stations. In [32], a group-based protocol and mobility model has been proposed to provide ubiquitous Internet access to vehicles. They have demonstrated that vehicles inside each group can move while the groups can vary in size and have given a mobility model for such network. In [33], a three-layered network architecture has been proposed for social services in vehicular networks. They proposed a dynamic social group formation and management mechanism using a middleware service. Pop *et al.* [34] introduced a context-based algorithm for vehicular networks where nodes' online social connections are leveraged to extract information such as interest, and contact history. They demonstrated that network congestion can be reduced by using this context information for the dissemination of messages. In [35], a friendship recommendation mechanism has been introduced which recommends friends based on lifestyle instead of a social graph. Moreira *et al.* [36] have shown that social aware forwarding in communication networks can improve the data delivery by as much as 60% in disruptive scenarios. In [6], authors show different scenarios for VSNs and how content dissemination is different in VSNs than other networks which can be of great use. Very recently Kong *et al.* [37] proposed a mobility dataset generation method for VSNs using floating car data and social functional areas. However, the mobility model presented is restricted to urban functional areas and may not represent social vehicles in few spots such as train stations or airports. In [38], we designed a social acquaintance-based routing protocol for VSNs where social utilities are derived to deliver a message to a specific node. These findings have motivated us to explore the opportunities VSNs offer for the dissemination of EWMs.

3. SYSTEM OVERIVEW

Unlike Social Internet of Vehicles (SIoVs), where vehicles are key social entities for Machine-to-Machine (M2M) relationships, in VSNs, users are key social entities and the social relationships of the drivers are taken into account [39]. Therefore, we consider the network as a social graph $G(V, E)$, where $V = \{v_1, v_2, \ldots, v_N\}$ is the set of vertices whose each entry represents an individual user, while $E = \{e_1, e_2, \ldots, e_N\}$ is the set of edges, where each entry represents social links between two nodes. Moreover, VSN architecture incorporates social groups based on the interests of the drivers. The proposed scheme takes advantage of this feature to broadcast EWMs

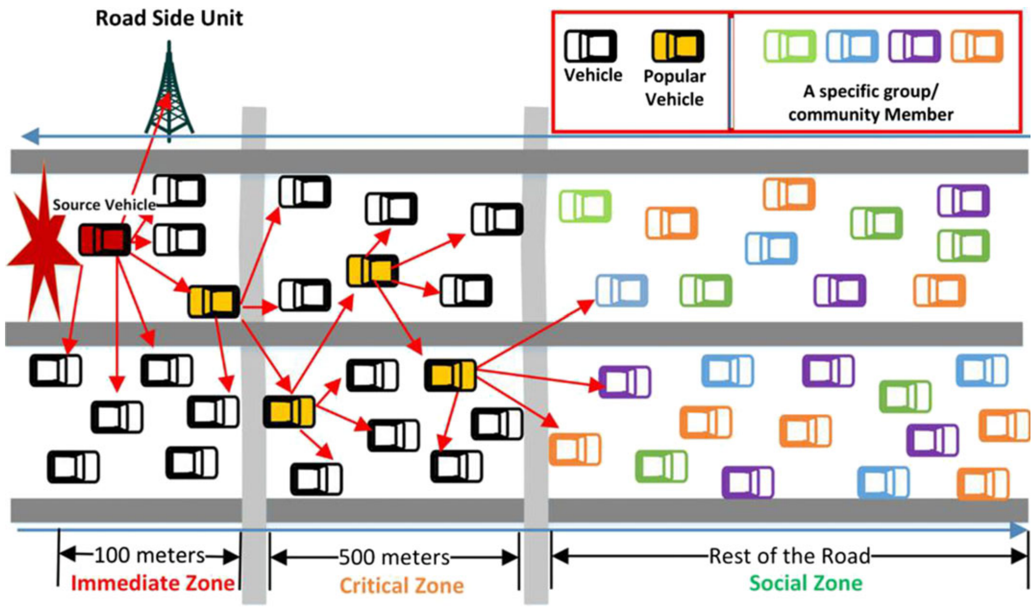

FIGURE 1. The zonal division and road layout for the proposed scheme. (Coloured version is available online.)

inside the social groups instead of individual transmission whenever possible. Therefore, SUDS maintains a group vector $G = (IG_i, \ldots, IG_N)$, where each entry represents, a specific set of nodes $M = \{1, \ldots, x\}$, having similar interests, which can be updated over time. Similarly, each node may have a finite set of interests, $I_i = \{1, \ldots, m\}$. These social parameters along with centrality of the nodes are considered for the selection of broadcaster.

All vehicles are assumed to be equipped with *GPS* navigation for position and location information, On-Board Unit (OBU) for *DSRC*-based communication and other functionalities. SUDS utilizes the hybrid architecture of VSNs, where vehicles can communicate in dual-mode namely Vehicle-to-Vehicle (V2V) mode and Vehicle-to-Infrastructure (V2I) mode. The communication in V2V mode is carried out via DSRC where drivers can directly engage in communication with others via OBUs in a distributed ad hoc social network. However, due to short range of communication and heavy network traffic, users may benefit from V2I mode. In V2I mode, drivers can connect with other drivers, social groups and even Internet via Road Side Units (RSUs) and 3G/4G cellular communication. Moreover, V2I mode offers centralized supervision of communication, where a central entity manages the communication process. This ensures secure and reliable information transfer. In this way, the hybrid model of VSNs ensures the uninterruptible availability of communication links.

A highway scenario is considered where the road section is divided into three distinctive zones based on the distance from the accident location. The road layout and communication process is given in Fig. 1. We consider that the risk near the accident location is higher, therefore, we define the immediate zone as the area under 100 m of distance from the source vehicle. In this zone, very immediate response is required and hence blind broadcast is considered to inform all the vehicles in range. The next zone is critical zone where the risk factor is intermediate and is defined as the area between 100 and 600 m from the source vehicle. In this zone, social centrality is utilized for dissemination of EWMs. Finally, the rest of the road section is considered as the social zone where the risk factor is lower than the rest of the zones. In this zone, groups and friendship-based broadcast is utilized. Therefore, SUDS adopts multiple broadcast strategies based on the risk factor of the zones. So the broadcaster selection criteria (S_c) can be a function of multiple factors such as Geographic Information (G_i), Risk Factor (R_f), Vehicular Speed (V_s), Social Utility (S_u) and Resource Availability (R_a) and is given as

$$S_c = f\,(G_i,\, R_f,\, V_s,\, S_u,\, R_a).$$

Figure 2 shows a flow diagram of SUDS. In case of an emergency, a SUDS powered vehicle will generate an EWM to its nearest neighbors. Through EWM, the source vehicle will share its location with other vehicles and RSUs. In this way, different zones can be defined based on the risk factor. A decision will be made based on the availability of infrastructure support whether to activate V2V or V2I mode. Therefore, to achieve efficient and reliable dissemination, we devise a dual-strategy based on the availability of resources: (1) Infrastructure-Based Strategy and (2) V2V Strategy. In order to operate each strategy, we devise a framework of routines which can be installed on RSUs and OBUs. In the following subsections, we present an overview of the framework.

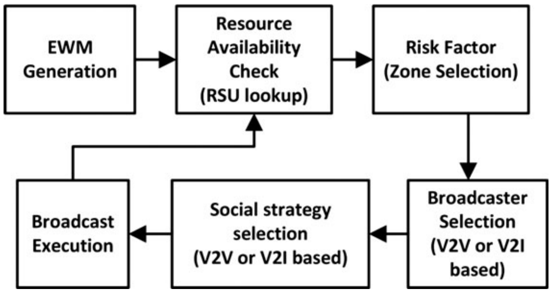

FIGURE 2. Flow diagram of SUDS.

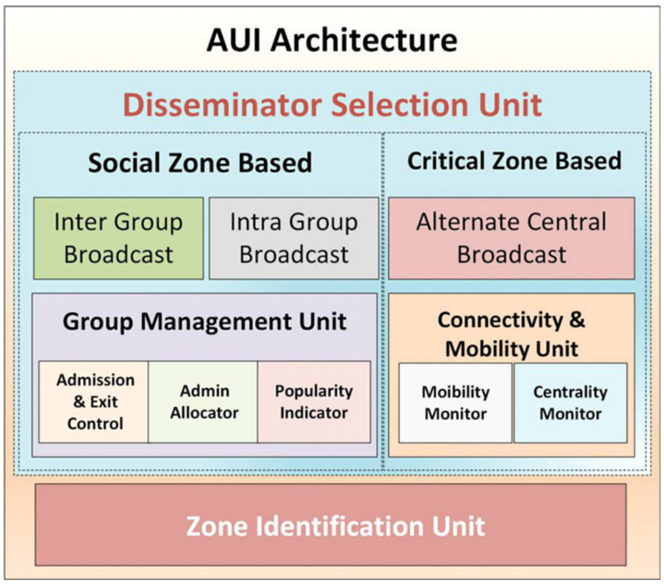

FIGURE 3. Block diagram of AUI architecture.

3.1. Infrastructure-based strategy

The high end reliability of 3G/4G services enables us to use hybrid model of VSNs more easily. Therefore, we introduce an administrative unit, AUI (Administrative Unit for Infrastructure), that will be installed at RSU to carry out dissemination process under specific circumstances. The basic purpose of this unit is to oversee the social and network connections of nodes, their group affiliations and management, and decision making for broadcaster selection. Figure 3 depicts the block diagram of AUI architecture. Below we give details of the different units of AUI and their operation.

3.1.1. *Zone identification unit (ZIU)*

The main purpose of this unit is to locate a vehicle on the road and categorize it into one of the three zones of the road mentioned in Section 3. It basically keeps a record of GPS location data of the vehicles along with their time stamps, and speeds. Based on the distance from the source vehicle, it decides which vehicle falls into which particular zone. For example, if vehicle i is moving with certain velocity v and is present at position (x_i, y_i), then it calculates its translational distance, $D_{\mathrm{tr}(i)}$ from the source vehicle s present at (x_j, y_j) as

$$d_{(i)} = \sqrt{((s_x - i_x)^2 + (s_y - i_y)^2)},\\ d_{\mathrm{tr}}|_{i=1}^{n} = |s_y - i_y||_{i=1}^{n}, \tag{1}$$

where s_y and i_y represent ordinate values of the source vehicle and vehicle i on a 2D grid, respectively. All these distances are stored in the *distance list* $d_{(\mathrm{tr})}|_{i=1}^{n}$. As we are dealing with high mobility nodes, it is of utmost importance to take *vehicular speed* into consideration. Therefore, the *distance lists* of nodes will be updated after a time interval Δt, and this process will continuously run in real-time, determining vehicles in different zones. These values are stored in *Zone Identification list*, Z_{id} of each vehicle in the network i.e. $1, \ldots, n$, at any instant of time t as

$$Z_{id}|_{i=1}^{n} = (d_{\mathrm{tr}}|_{i=1}^{n})|_t. \tag{2}$$

If $Z_{id\,(i)} < 100$, then vehicle i will be categorized in immediate zone, otherwise if $100 \le Z_{id\,(i)} \le 600$, then it will be put into critical zone. All vehicles that get a value beyond 600 will be considered in social zone.

3.1.2. *Connectivity and mobility unit (CMU)*

In order to take care of the message propagation, CMU performs two important tasks that are (1) to find out inter-connectivity among the nodes and (2) to identify the lanes and determine the movement direction of the nodes. The main focus of CMU is to take care of dissemination in the critical zone. As in the critical zone, the urgency of the situation is much higher, store-carry-and-forward propagation model may not be feasible due to a lesser number of the vehicles in the zone. On the other hand, established social connections among the nodes can be taken into consideration for rapid dissemination. These connections are rather stable and can be easily tracked down with the help of a centralized entity. Moreover, such one-hop connections can be quantified into a key metric called centrality, which gives us important nodes in a network. This can be achieved by *degree centrality* calculation for a certain node i, which is given as

$$D_i = \sum_{j=1}^{N} c(i, j), \tag{3}$$

where $c(i, j) = 1$ if there exists a connection between nodes i and j, and 0 otherwise. Therefore, CMU first identifies the established connections among nodes and calculate their *degree centrality* values according to Equation (3). However, the network topology can alter rapidly in VSNs because of the high mobility of nodes. Therefore, time must be considered a key factor in calculation of D_i, and hence for any node, *degree centrality* at any time interval Δt can be written as

$$D_i(t+\Delta t) = \alpha D_i(t) + (1-\alpha) D_i(t-\Delta t), \tag{4}$$

where $D_i(t+\Delta t)$ is the degree centrality at the next time slot, $D_i(t)$ is at the current time and $D_i(t-\Delta t)$ is at the previous. Here α is the weight factor such that $0 < \alpha < 1$. It shows the influence of current and past time degrees. The value of α can be used to shift the tendency of D_i to the recent or earlier time value. The centrality values for each vehicle are stored and updated as soon as there is a change in the network. From the GPS data, CMU also determines the propagation direction of the vehicles and keeps the record for utilization in the message propagation process.

3.1.3. *Group management unit (GMU)*

In order to keep a check on group affiliations and their exit and entrance, AUI makes use of the GMU. The function of GMU is 3-fold: (1) Controlling entrance of new nodes into the groups and exit of the already registered nodes; (2) Allocating administrator to each group that will be responsible for overseeing the activities in the group and will have broadcast capabilities; (3) To identify such group members that have joined the highest number of other groups. The group admission and exit control is based on a specific set of interests, $I = \{I_i, \ldots, I_n\}$ (where n is the maximum number of interests in the set) a group may have. Once a member applies to join a certain group, the GMU will check its interests I_v, and the number of current members of the group i.e. M_c. If their interests match and the maximum number of memberships is not yet reached, then the vehicle will be allowed to join the group. Based on this criterion, the admission control can return a Boolean value E equal to 0 or 1, which indicates rejecting or accepting the registration request respectively and is given as

$$E = \begin{cases} 1 & \text{if } I_v \cap I \neq 0 \text{ and } M_c \neq M_{\max} \\ 0 & \text{otherwise} \end{cases}. \tag{5}$$

After registration, GMU will alert the admin about the new entry which will pair the new node with itself creating a direct social connection. Similarly, if a node wants to leave a group, the GMU will update the group membership lists accordingly. Another important task is to assign a suitable group admin for a specific group. Usually the first member of the group will be selected as administrator of the group but as the number of members exceeds 10, the GMU will look for the most popular node in the group and will assign it the duties of administration such as, removing the misbehaving and malicious nodes, management of information sharing, and most importantly connecting with every member of the group.

Moreover, GMU identifies the nodes within a group that are members of other groups as well at the same time. For instance, if at time t, a node has joined a number of groups represented by the set J_g, then the value of $|J_g|$ indicates its inter-group connectivity index (IGC_i). GMU keeps a record of it and updates it as soon as its affiliations change over time interval Δt. Therefore, at any instance, the IGC_i for every member of the group is calculated using Equation (6), which is used in the broadcasting strategy:

$$\mathrm{IGC}_i(t) = |J_g(t) \cap J_g(t-\Delta t)|. \tag{6}$$

3.1.4. *Disseminator selection unit (DSU)*

This part of AUI selects the suitable candidate and mechanism for dissemination of EWMs in the critical and social zones. If ZIU feeds in that a vehicle falls in the critical zone then DSU decides to use alternate central broadcast mechanism, where nodes with highest degree centrality values are selected for broadcasting to their one-hop connections. After each iteration, a vehicle moving in the opposite direction is selected as broadcaster to ensure rapid dissemination. On the other hand, if a vehicle is in the social zone then social properties-based strategies are used for dissemination among the nodes, where group popularity and IGC_i values are taken into account to disseminate the messages within a specific group and among different groups.

3.2. V2V-based strategy

In case if infrastructure is not available for some reason or there is a network break down due to some issue, then VSNs provide V2V communication feature. Due to this facility, we can devise a dissemination strategy where vehicles communicate with other vehicles via DSRC. However, unlike infrastructure-based solution, we may not have the luxury to use degree centrality or group related features in V2V communication for dissemination. This is because in order to calculate degree centrality, a centralized entity is required to keep track of the network connections. Similarly, groups can also be managed more efficiently in the presence of a central administrative unit. On the other hand, other properties like social ties and betweenness centrality can both be managed and calculated in a distributed network architecture. In this mechanism, we get inspiration from [21], where social ties like similarity, betweenness centrality, and Tie-strength were combined for information flow in MANETs. However, our work is different as we use different utility function and focus on utilizing it in VSNs which are quite different and challenging than MANETs. Therefore, in this case, we use such properties locally at the On-Board Unit (OBU) to devise a dissemination strategy. As every device in a VSN is equipped with an OBU, we propose an Administrative Unit for Vehicles (AUV) within OBUs. Figure 4 depicts the block diagram of the AUV architecture. Following is the description of different parts of AUV.

3.2.1. *Time-betweenness utility calculator*

Betweenness centrality (BC) is a key metric in graph theory and network analysis, which shows the capability of a node to

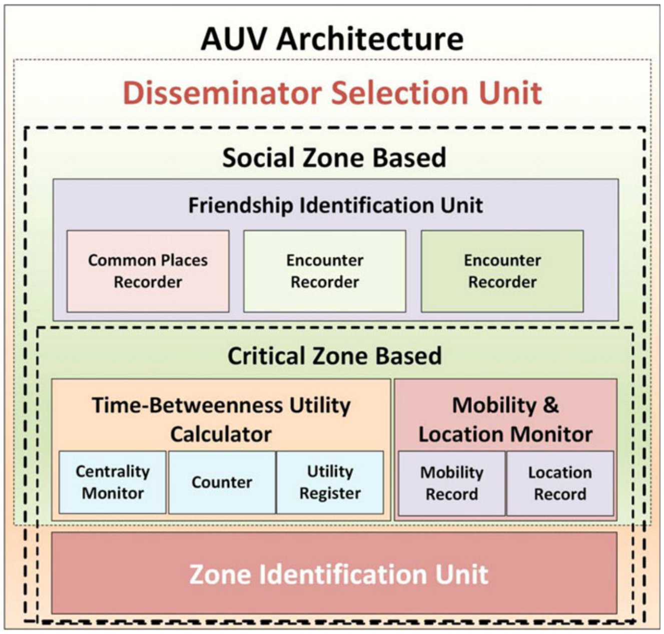

FIGURE 4. Block diagram of AUV architecture.

facilitate communication between other nodes. It is basically the measure of geodesic paths among other nodes passing through a given node i, and can be calculated as follows:

$$\mathrm{BC} = \sum_{j \neq i} \frac{gd_{j,k}(i)}{gd_{j,k}}, \tag{7}$$

where $gd_{j,k}$ denotes the total number of geodesic paths between nodes j and k, while $gd_{j,k}(i)$ shows the number of geodesic paths between j and k that pass through node i. BC is of importance in dissemination of messages in social networks as it controls the information flow in the network. In other words, a node with higher BC value will be able to spread the message among other nodes more efficiently as it can work as a bridge among a higher number of nodes. However, calculation of BC is more difficult if the size of network is too big. Therefore, ego networks can be explored, where a central node called actor is connected with other actors (called alters) that have links with other alters. Therefore, analysis and calculations for ego network can be done by the nodes locally without having full knowledge of the complete network. The contacts between nodes in an ego network can be represented by an $n \times n$ adjacency matrix A, where n denotes the number of encountered contacts of a node. The adjacency matrix entries will be then as follows:

$$A_{i,j} = \begin{cases} 1 & \text{if } i \text{ and } j \text{ have a connection} \\ 0 & \text{otherwise} \end{cases}. \tag{8}$$

We assume that nodes' contacts are bidirectional, i.e. if node i has a contact with node j then the reverse also holds true. Then BC of the ego node i can be calculated by finding out the number of nodes that are indirectly connected via node i. Therefore, ego betweenness of node i is then the sum of the reciprocals of $A^2[1 - A]_{i,j}$ [21]. Once the value of BC is calculated then a *betweenness utility* can be obtained for every node i to deliver a message to any node j in the network using Equation (8):

$$B_{u(i)} = \frac{\mathrm{BC}_{(i)}}{\mathrm{BC}_{(i)} + \mathrm{BC}_{(j)}}. \tag{9}$$

As the mobility of nodes in VSNs is much higher than that in MANETs, the utility of nodes will also change as the time progresses. Therefore, this utility function cannot be simply taken into account without considering the time factor. So we take into account the change in $B_{u(i)}$ over time Δt as

$$B_{u(i)} = \left. \frac{\mathrm{BC}_{(i)}}{\mathrm{BC}_{(i)} + \mathrm{BC}_{(j)}} \right|_t, \tag{10}$$

and

$$B_{u(i)}(t + \Delta t) = \beta B_{u(i)}(t) + (1 - \beta) B_{u(i)}(t - \Delta t), \tag{11}$$

where $B_{u(i)}(t + \Delta t)$ is the updated *time-betweenness utility* at next time slot based on the values of current and previous time intervals. The term β is a weight factor that determines the present and past influence of the utility. The value of β can be tuned such that $0 < \beta < 1$. The values of α and β can affect the dissemination process because of high mobility of nodes. Therefore, to obtain suitable values, we have conducted experiments that are discussed in Section 5.

3.2.2. *Friendship identification unit (FIU)*

Although similarity of nodes can be of high importance for routing in VSNs, it does not have much impact in critical situations. This is because in such systems message dissemination to a massive crowd is required instead of finding a similar node to deliver a message in store-carry-and-forward manner. However, the friendship between nodes can be of great importance as gossip spreads among friends faster than strangers. Moreover, friendships among nodes are relatively stable than other social metrics e.g. centrality, and hence can be used for dissemination in the social zone on the road. Therefore, in our proposed scheme, we employ this social property for rapid dissemination.

Many works in social networks have identified that frequent contacts among nodes and the receceny of their encounters indicate friendship among the nodes. However, we observe that besides these metrics, interests of people also have a great impact on their friendships. Therefore, the main purpose of FIU is to collect data about the contacts between nodes, their encounters in common places, and their common interests. By combining these metrics, we can obtain a friendship index for every node that is relatively stable with time. For instance, if nodes i

and j contact each other (where we take the contacts as bidirectional), then their contacts history can reveal us the number of times they have contacted each other, over a given amount of time This information is stored in an encounter record list, $E_{(i,j)}|_{j=1}^{N}$ of each vehicle i for all other vehicles in the network i.e. a total of $N-1$. The base value of $E_{(i,j)}$ is kept at 1 which is incremented upon every encounter. Accordingly, their common interest degree I_d can also be quantified as

$$I_d = \left| \frac{I_i \cap I_j}{I_i \cup I_j} \right|, \tag{12}$$

where I_i and I_j represent the sets of interests of nodes i and j, respectively. The value of I_d can, therefore, be such that $0 \leq 1_d \leq 1$. Similarly, the degree of their visits to common places, V_d, can also be calculated as

$$V_d = \left| \frac{V_i \cap V_j}{V_i \cup V_j} \right|, \tag{13}$$

where V_i and V_j represent the sets of their visited places and $0 \leq V_d \leq 1$. Then using the indicators obtained in Equations (12) and (13), i.e. I_d, V_d, respectively, and the value of $|E_{(i,j)}|$, we can derive a friendship indicator function between any nodes i and j as

$$F_{\text{Indicator}(i,j)} = \rho I_d + \sigma V_d + \gamma\, |E_{(i,j)}|, \tag{14}$$

where $|E_{(i,j)}|$ denotes the number of times i and j contacted each other, and ρ, σ, γ are normalization constants and can be varied to increase the influence of any factor in above equation. From Equation (14), we can then derive a generalized friendship index for each node as follows:

$$F_{\text{index}(i,j)} = 1 - \frac{1}{F_{\text{Indicator}(i,j)}}. \tag{15}$$

The value of $F_{\text{index}(i,j)}$ will, therefore, ranges between 0 and 1. By utilizing the capabilities of OBU, each node's AUV can keep a list of its friends locally using Equation (15), which is stored in its friends-list of FIU. In order to reduce the overhead of broadcasts, we limit each node's friends by selecting only the highest 10 values of F_{index} in its list.

3.2.3. Mobility and location monitor (MLM)

The main objective of this unit is to identify the location of the vehicle via GPS, measure the distance between the source vehicle and the host vehicle, and determine the direction of the mobility. This unit is the same as the one in AUI which is explained in detailed.

3.2.4. Disseminator selection unit (DSU)

This part is the decision-making unit of AUV that determines which node should be selected to broadcast the EWMs? Moreover, it also determines the zonal location of the vehicles on the road, based on which specific broadcast strategy is utilized.

4. WORKING OF SUDS

In this section, we give a detailed description of the operation of SUDS in a highway scenario. As described in Section 3, we divide the road into three zones based on the urgency of the situation. Figure 1 depicts the road layout. We will break down the operation into different zones for a better understanding.

4.1. Immediate zone dissemination strategy

This zone is the most sensitive area of the road; therefore, vehicles in immediate zone require a more rapid dissemination of EWMs. In our proposed scheme, the immediate zone is considered as the area covered by 100 m behind the source vehicle and can be computed using Equation (1). The most important parameter here is transmission delay which should be as least as possible. Therefore, in case of an emergency on the road, the affected vehicle or the first vehicle that witnesses the event will generate an EWM and broadcast it periodically every second to all the vehicles and RSUs in its communication range via DSRC. Because the number of vehicles is not much higher in such a small area, the flooding mechanism will not be affected by broadcast storm problem significantly. The message header will contain time stamp of the generated message, ID and location of the source vehicle (via GPS data), and the type of emergency, which is given in Table 1.

The received vehicle compares its location with the source vehicle's location and sends an acknowledgment message containing its ID and position. In case if infrastructure is available, then RSU will disseminate message among the vehicles in the immediate zone.

4.2. Critical zone dissemination strategy

The delicacy of the situation decreases when moving away from the source vehicle. However, the danger of any serious mishap, such as rear-end collision of vehicles, is still a possibility. We call this area of the road as critical zone and keep it to 500 m from the immediate zone, which can be altered based on road scenario. Therefore, we can trade-off a little delay with network overhead in the critical zone. This is to ensure that broadcast storm problem does not affect the network communication and dissemination efficiency. The proposed scheme utilizes some network and social properties to disseminate EWMs in this zone. SUDS uses the hybrid model of VSNs to ensure the reliability of the dissemination process. If any RSU is in range, then infrastructure-based broadcast mechanism is adopted via V2I communication. On the other hand, if for some reason infrastructure cannot be accessed, then local V2V mechanism is adopted using the AUV system embedded in OBUs of the nodes. Our proposed algorithm for dissemination in critical zone is given in Algorithm 1. Table 2 lists the abbreviations used in Algorithms 1 and 2.

In case of infrastructure availability, SUDS considers three important factors for broadcaster selection criteria, i.e. (1) *time-Degree Centrality* which is obtained from Equation (4); (2) speed of the vehicles which is obtained by mobility and location monitor; and (3) distance from the source vehicle, $d_{\mathrm{tr}(i)}$ which is stored in ZIU. As vehicular speed is directly proportional to the connectivity of network; therefore, vehicle with a lesser speed is given priority over the higher speed ones. Moreover, as the neighbors of closer vehicle may be already alerted, SUDS chooses the vehicle with highest d_{tr} value. Thus AUI can calculate Speed-Degree Priority, $\mathrm{SD}_{\mathrm{Priority}}$ using Equation (16), and store it in the broadcaster-selection priority list:

$$\mathrm{SD}_{\mathrm{Priority}\,(i)} = \frac{D_i\,(t + \Delta t)}{V_{\mathrm{Speed}}}. \tag{16}$$

A node with highest value of $\mathrm{SD}_{\mathrm{Priority}}$ is selected to broadcast EWMs to its one-hop connections. In case if multiple nodes have equal $\mathrm{SD}_{\mathrm{Priority}}$, then the node with highest d_{tr} value is selected as the broadcaster. Once a node broadcasts the message, then AUI looks for the highest $\mathrm{SD}_{\mathrm{Priority}}$ value among the received nodes on the opposite lane of the road. This is because with their mobility direction it is more likely that they can reach out to the nodes that are nearer to the danger area. So vehicles on alternative lanes are selected in every iteration. On the other hand, in V2V-based strategy, the *time-betweenness utility* calculated in Equation (11) is utilized to select the broadcaster in this zone. This is because degree centrality calculation for such a high mobility distributed system is not feasible in emergency situations. However, vehicular speed also has an impact on the reliable information flow; therefore, a vehicle with lower speed and higher *time-betweenness utility* is selected to broadcast the message in its communication range. Like infrastructure-based mechanism, here also cross-lane broadcast is carried out until the limit of critical zone is reached.

TABLE 1. Emergency warning message header format.

Emergency warning message header			
Initiation Time	Vehicle ID	Location of Source vehicle	Emergency Type

TABLE 2. Abbreviations used in Algorithms 1 and 2.

Abbreviation	Meaning
IS	Infrastructure-based strategy
V2VS	V2V dissemination strategy
Rc	Critical zone range
R	Current position
OL	Opposite lane
$m_o d$	Mobility direction
IG	Interest group
F	Friends-list
$m_s d$	Message direction
CZ	Critical zone
SZ	Social zone

Algorithm 1 Pseudocode for dissemination strategy in critical zone.

Initiation: Nodes in CZ receive EWM from IZ
if RSU is in range
  Initiate $\rightarrow$ IS
  for R $\leq$ Rc
    Calc $\rightarrow |Di|_i^N$ for $Nodes = [i, \ldots, n]$
    Calc $\rightarrow \mathrm{SD}_{\mathrm{Priority}}|_i^N$
    Select node $i \rightarrow$ max $(\mathrm{SD}_{\mathrm{Priority}}, d_{\mathrm{tr}})$
    Initiate Broadcast $\rightarrow$ 1-hop links
    $Nodes = [i + 1, \ldots, n]$
    if 1-hop links exist $\rightarrow$ OL
      Select nodes $\rightarrow$ OL
    end if
  end for
else if RSU is not in range
  initiate $\rightarrow$ V2VS
  for R $\leq$ Rc
    Calc $\rightarrow B_u(t + \Delta t)$ for $Nodes = [i, \ldots, n]$
    Select node $\rightarrow (maxB_u(t + \Delta t), minV_{\mathrm{Speed}})$
    broadcast $\rightarrow$ in range
    $Nodes = [i + 1, \ldots, n]$
    if node $\rightarrow i$
      $m_o d_{(i)} = m_s d$
      $B_{u\,(i)}(t + \Delta t) = maxB_u(t + \Delta t)$
      select node $\rightarrow (maxB_u(t + \Delta t), minV_{\mathrm{Speed}})$
      broadcast $\rightarrow$ in range
    end if
  end for
end if

4.3. Social zone dissemination strategy

By the time EWM reaches the social zone i.e. almost 600 m away from the source vehicle in our proposed scenario, the danger is significantly reduced due to efficient dissemination of Algorithm 1. In this zone, then SUDS completely depends on the social properties of VSNs to spread the EWM among the nodes stretched over a long distance. Therefore, it incorporates a complete social utility-based dissemination in social zone utilizing the metrics introduced in Section 3. Here again, reliability is achieved by employing both V2I and V2V features of VSNs. Therefore, wherever communication with RSU is available, it carries out the infrastructure-based routine via 3G/4G cellular network. The social properties like interest groups and centrality are utilized to carry out the dissemination process via communication between OBUs of the nodes and AUI in the RSU. In case of lack of communication with RSU, the AUV in OBU takes control of the dissemination process by utilizing friendships and time-betweenness utilities introduced in Section 3. The pseudocode for dissemination in social zone is given in Algorithm 2.

When the infrastructure-based strategy is utilized, the vehicles are categorized into different interest groups based on their interests e.g. sports, news, entertainment, etc. The AUI manages these groups and keeps records of all the members and their affiliations within and outside the groups. When it receives an EWM, AUI informs the administrator of every group to disseminate it in its group. As, many nodes may have joined multiple groups so AUI identifies the nodes with highest IGC_i value in each. The selected node is directed to inform the admins of all groups that it has joined. In next iteration, the same procedure is repeated until all the nodes are alerted about the situation. Figure 5 depicts an example scenario of this process.

On the other hand, in V2V mechanism, group-based strategy may not be feasible because of the lack of reliable centralized administrator. Therefore, SUDS employs the friends-list introduced in Section 3 along with time-betweenness utility to disseminate the message in the social zone. The AUV in OBU of node identifies its friends and then notifies them via direct broadcast. At the same time, the friends that are being informed are evaluated for time-betweenness utility. The friend that has the highest value is selected as a suitable candidate for broadcasting, and the process is repeated. Meanwhile, the search for RSU is carried out periodically and if a connection is established, the AUI takes over AUV and infrastructure-based strategy is resumed.

Algorithm 2 Pseudocode for dissemination strategy in social zone.

Initiation: Nodes in SZ receive EWM from CZ
If RSU is in range
  Initiate $\rightarrow$ IS
  for $1 < x \leq N$
    $|IG|_{i=1}^{N}$ Identify $\rightarrow$, $admin\,(IG_i)$
    for $1 < x \leq n$
      calc $\rightarrow (\mathrm{IGC}_i)_x$
    end for
    inform $\rightarrow admin\,(IG_i)$
    permit $\rightarrow$ broadcast in host IG
    Select node $\rightarrow \max(\mathrm{IGC}_i)$
    forward $\rightarrow$ admins of host IGs
  end for
else if RSU is not in range
  initiate $\rightarrow$ V2VS
  for $R \geq Rc$
    Identify $\rightarrow F = [1, \ldots, M]$ of i
    broadcast $\rightarrow$ F
    If RSU $\rightarrow$ in range of F
      Jump $\rightarrow$ step 1
    else
      determine $\rightarrow B_u(t + \Delta t)|_{j=1}^{M}$
      select node$(max\ B_u(t + \Delta t),\ min\ V_{\mathrm{Speed}})$
      broadcast $\rightarrow$ in range
    end if
  end for
end if

5. SIMULATION SETUP AND PERFORMANCE EVAULATUION

5.1. Simulation setup

In order to analyze the performance of SUDS, extensive simulations were performed under highway scenario. The reason to use simulation for evaluation is that there is no standardized

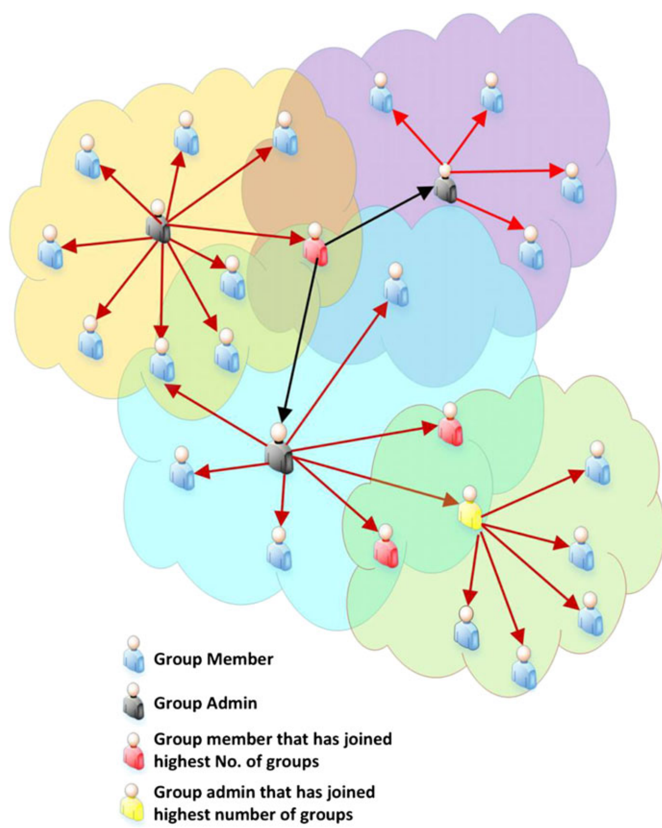

FIGURE 5. Depiction of group-based dissemination with different actors involved in the process (Coloured version is available online.). The red arrows indicate broadcast from group admin to the group members. The black arrow indicates the selectively forwarded message by the group member, who has joined the maximum number of groups to the admin of another group that he has also joined.

dataset available at the moment for social properties-based communication scenarios in VSNs. Moreover, most of the works in the literature used simulation-based evaluation of synthetic or realistic mobility traces. We compare SUDS with four state-of-the-art protocols for dissemination in networks that use either social metrics-based strategies or partially incorporate store-carry-and-forward mechanism. The compared protocols are described below:

- *DV-Cast* [16] which is proposed to cope with varying density of vehicles in vehicular networks. It uses one of the three different proposed suppression techniques, where we consider the most efficient one, the slotted 1-persistence in our simulations.
- *AMD* [17] is a scalable protocol for the dissemination of messages in VANETs both under the highway and urban scenarios. It uses an adaptive directional mechanism along with store-carry-and-forward algorithm for dissemination specifically in straight highways.
- *SimBetTS* [21] is a dissemination protocol that utilizes the social properties such as similarity, centrality and tie strength among the mobile nodes. It is closely related to our protocol because both of the techniques use social properties; therefore, we selected it for comparison.
- *Socially Inspired Data Dissemination Protocol (SIDD)* [29] is a social metrics-based data dissemination protocol for highway scenarios. It utilizes clusters formation and centrality to select the next forwarder in the network.

For simulation scenario, we consider a 2.5 km long section of a highway in Dalian city, China, using Openjump software that creates open source GIS-rich maps. We consider random waypoint model for trip generation in order to extract mobility traces using VANETMobiSim. To create more VSN like scenario by incorporating social attributes and communication mechanism, we simulated the traces using the ONE (Opportunistic Network Environment) simulator for our proposed scheme. ONE simulator is a JAVA-based software that gives more flexibility to define different social attributes, for example, interests, friendships, similarity, etc., for our scheme using JAVA APIs. In order to evaluate the scalability of the proposed scheme under dense and sparse environments, we consider multiple vehicular density (vehicles/kilometer) values. Similarly, vehicles' speed also affects the efficiency of communication and connectivity among the vehicles. Therefore, we conducted experiments with varying speeds of vehicles ranging from 60 to 120 km/h. We assume that RSUs are installed at random locations on different sections of highway. Table 3 summarizes the details of different simulation parameters in our experiments. We had five runs of the simulations and the results presented here are the averages of those simulations. For implementation and simulation of our scheme, we assume that all nodes are fully cooperative for simplicity purposes.

5.2. Performance evaluation

We evaluate the performance of SUDS under varying density, distance and speed of vehicles for the following parameters and compare them with the aforementioned protocols:

- *Delivery ratio* is a network measurement parameter which is defined as the ratio of number of receiving nodes to the total number of nodes in a network. In ideal scenario, a dissemination protocol should achieve a 100% delivery ratio in dense networks.
- *Transmission delay* is the total time taken by the generated message to fully propagate in the network covering the whole scenario. The value of transmission delay should be reduced as much as possible in order to ensure quick dissemination of EWMs in the network.
- *Number of transmissions* is the total number of transmitted messages in the network covering the whole scenario. The value of this parameter is normalized based on the total number of vehicles in a specific scenario. In order to avoid network congestion and broadcast storm problem, the total number of transmissions should be as low as possible.

Moreover, we evaluate the efficiency of proposed scheme under hybrid and completely distributed models. In the distributed model, we exclude the infrastructure support for communication in order to assess the effects of different parameters on the efficiency of social-based schemes. In addition to it, we investigate the impact of degree of social parameters' recency by varying values of weight factors α and β. In the following subsections, we present the results and discussion of the experiments:

5.2.1. *Vehicular density*

Density is an important indicator to evaluate the scalability of a network. Therefore, in the highly dynamic vehicular environment, varying vehicular density can indicate the effectiveness of a

TABLE 3. Description of simulation parameters.

Parameter	Value
Network simulator	ONE simulator
Trip generation	Random waypoint
Simulation duration	2000 s
Node density (vehicles/km)	10–70
Road length	2.5 km
No. of lanes in each direction	3
Speed of vehicles	60–120 km/h
No. of RSUs	10
Transmission range of a node	80 m
Transmission range of RSU	300 m
MAC protocol for V2V	IEEE 802.11p

dissemination protocol. Figure 6a shows values of the delivery ratio of each protocol against varying vehicular densities. From the results, we observed that SUDS outperforms all the other protocols under sparse and dense scenarios. The reason for this is that SUDS relies on social connections among the nodes. Although at lower densities, chances of finding social connections are reduced, the zonal division and multi-strategy-based mechanism of SUDS overcomes this issue. It can also be observed that apart from DV-Cast, all the protocols have a direct relationship between vehicular density and delivery ratio. This is because as the network gets denser, more social connections can be utilized to select the most suitable forwarder to disseminate EWM among their peers.

In Fig. 6b, we show the transmission delay of all the protocols with varying vehicular density. We observed that apart from AMD, SUDS outperforms all other protocols by a significant margin. The results indicate an inverse relationship between network density and transmission delay for most of the protocols. SimBetTS exhibits the highest delay at lower density because of the high mobility of vehicles, their social utility values are not utilized properly. However, DV-Cast shows an upward trend in delay with increasing density and has the highest delay at higher densities. The reason for this is the higher contention time taken by vehicles to re-broadcast in one-time slot. AMD has the least delay throughout, however, as the network density increases, the difference between AMD and SUDS also decreases significantly from nearly 14% at lower density to 0% at high density. This is because of the fact that SUDS utilizes social metrics along with hybrid transmission mechanism, which takes some processing and decision-making time. Moreover, the number of highly central nodes also starts increasing due to which messages can be delivered to a higher number of vehicles in reduced duration. Similar is the case with SIDD where initially the delay is very high but with increased vehicular density it exhibits a downward trend. However, it still lags behind SUDS by nearly 80% at higher densities while by a huge margin at lower densities.

Figure 6c shows a comparison of all the protocols in terms of total number of transmitted messages with varying values of vehicular density. It can be observed that SUDS outperforms all the protocols with the least number of transmissions followed by AMD, SimBetTS and SIDD. From the results, it is obvious that all the protocols show a downward trend in total number of transmissions with increasing vehicular density apart from DV-Cast where a higher number of re-broadcasts causes more transmissions. The reason for this behavior in AMD is its controlled mechanism of time slots allocation. On the other hand, in social-based schemes, this behavior is related to the higher utility of social attributes with an increased number of highly social and central nodes. Overall SUDS achieves approximately 9%, 15%, 21% and 27% better performance than AMD, SimBetTS, SIDD and DV-Cast, respectively.

From the above results, it can be deduced that SUDS is more scalable than the rest of the protocols. It achieves significantly better delivery ratio with the fewer number of transmissions than the others along with acceptable transmission delay.

5.2.2. *Road length*

The distance from the source vehicle can be seen as an indicator of the stability of a dissemination protocol. As a higher number of nodes are covered in the network, network parameters may show diverse trends under different scenarios. In Fig. 7a, we show the impact of road length on the delivery ratio of each protocol under a constant vehicular density. It can be seen that the delivery ratio of SUDS stays stable with a variation of only 1.2% between 0.5 and 2.5 km distance because of its dual dissemination strategy. SIDD and SimBetTS exhibit increasing trends with a variation of almost 13% between 0.5 and 2.5 km distance. AMD and DV-Cast initially show an upward trend but soon their performance starts degrading with further increase in distance. The reason is that the former two utilize social properties where increasing distance adds more social nodes to the network and hence improved performance, while the latter two face issues like re-broadcasting due to multiple vehicles competing for a single time slot.

Figure 7b shows the effect of distance on the transmission time of each protocol for disseminating the EWM toward the farther

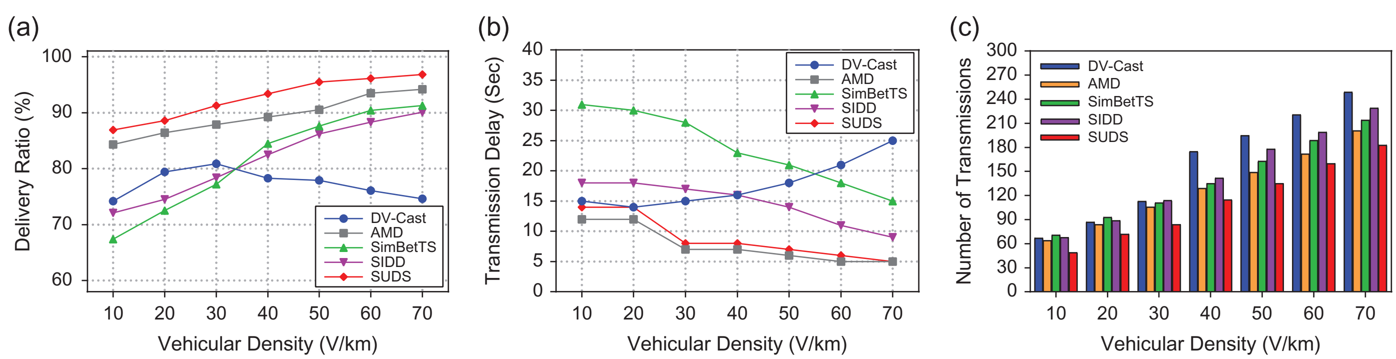

FIGURE 6. Effects of vehicular density on (**a**) delivery ratio, (**b**) transmission delay and (**c**) total number of transmissions. (Coloured version is available online.)

section of the road under constant vehicular density. While delay increases in AMD and DV-Cast because with increased distance, more nodes are added to the network, SUDS and other social-based protocols exhibit a downward trend. Initially, AMD achieves the least delay but after 1 km the delay increases rapidly with a total variation of about 56% because of the processing time for selection of next forwarder and contention for slot allocation. However, SUDS shows stability with an improvement of about 23% and also achieving a lower delay than AMD because of its social utility-based strategy and hybrid architecture. SimBetTS has the highest delay initially but over the distance, its delay decreases and ends up with an average delay. SIDD achieves better results than others but lags behind SUDS by almost 45%.

In Fig. 7c, we have compared the protocols in terms of the total number of transmission with increasing the road length. The error values for each protocol are also shown with reference to the ideal number of transmissions. As the road length increases, more vehicles are included in the network due to which there is an increasing trend in the number of transmissions. However, a stable protocol must not be affected by such increase and should stay within fair bounds of its transmission efficiency. The results indicate that SUDS not only stays relatively stable but improves its efficiency with an increasing number of vehicles. A similar trend is followed by SIDD and SimBetTS while DV-Cast's performance degrades throughout. Despite the initial improvement, AMD's performance degrades as the distance increases.

5.2.3. *Vehicular speed*

Due to the high mobility of vehicles, vehicular networks suffer from connectivity issues. Therefore analyzing network parameters by varying vehicular speed can indicate the robustness of a dissemination protocol. Figure 8a shows the delivery ratio with varying vehicular speed under a constant vehicular density. It can be observed that delivery ratio decreases with an increase in speed for each protocol. However, SUDS remains relatively stable until 90 km/h speed is attained because of its relatively stable social attributes along with infrastructure support. For AMD and DV-Cast, the decline in the delivery ratio is because of multiple factors including connectivity issues at higher speed and failure in the selection of suitable forwarder. Despite the use of social properties, SIDD and SimBetTS also suffer the same problem.

Figure 8b and c shows the impact of vehicular speed on transmission delay and number of transmissions, respectively, under constant vehicular density. In terms of the total number of transmissions, SUDS outperforms rest of the protocols followed by AMD. However, in terms of transmission delay, SUDS lags

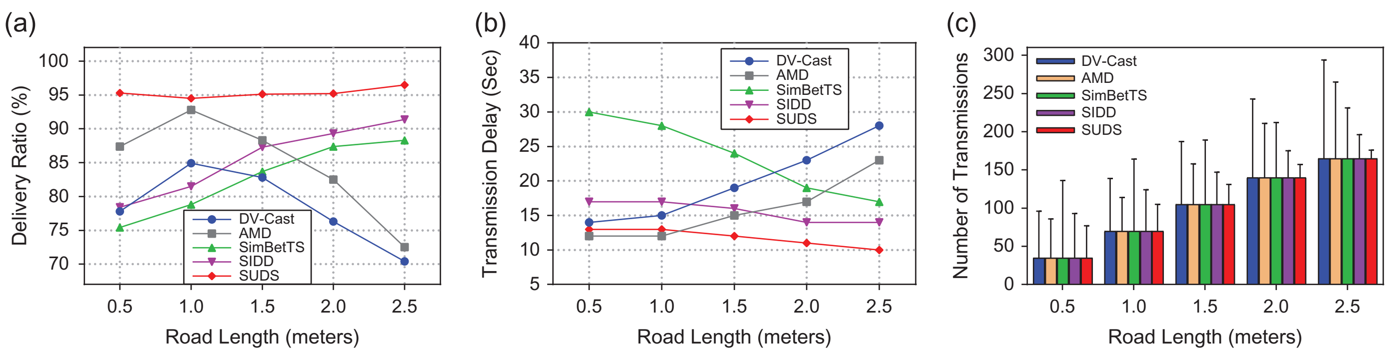

FIGURE 7. Effects of distance on (**a**) delivery ratio, (**b**) transmission delay, and (**c**) total number of transmissions. (Coloured version is available online.)

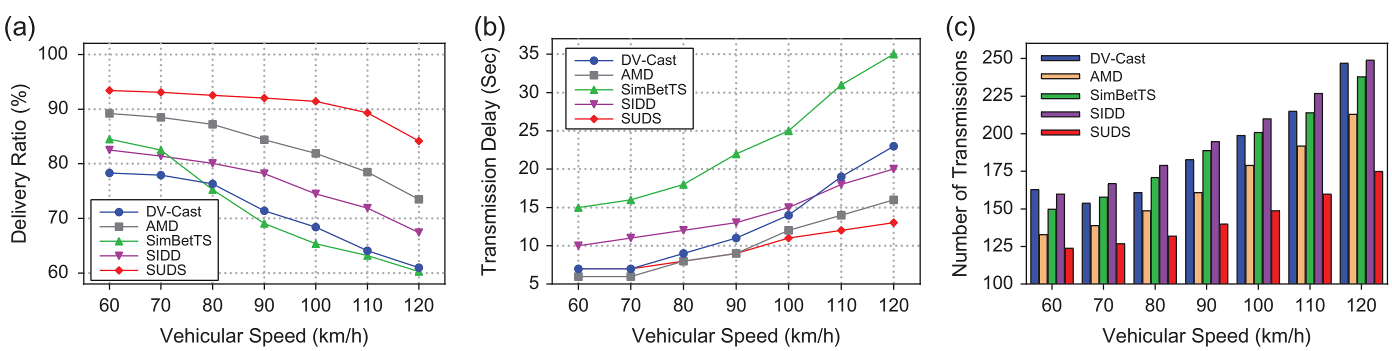

FIGURE 8. Effects of vehicular speed on (**a**) delivery ratio, (**b**) transmission delay and (**c**) total number of transmissions. (Coloured version is available online.)

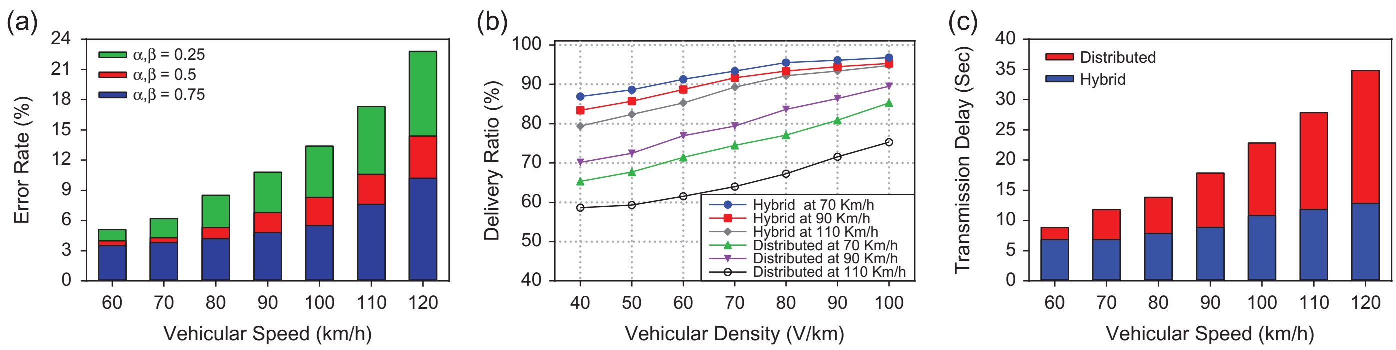

FIGURE 9. (**a**) Effect of time weight factors on social utility; effect of Infrastructure support on (**b**) delivery ratio and (**c**) transmission delay. (Coloured version is available online.)

behind AMD initially but catches up with it very soon and at around 75 km/h both have the same delay, while at very high speeds, SUDS performs even better than AMD. The reason for this is at very high speeds AMD suffers from connectivity and contention delay issues. Even at lower speed, the difference between these two is not very high and is acceptable because of the difference in the nature of both network models. Performance of the rest of the protocols degrade significantly at higher speeds. These results validate the robustness of the proposed protocol under high mobility conditions.

5.2.4. *Effects of infrastructure support and weight factors α and β on the performance of SUDS*

Figure 9a shows the deviation in delivery ratio from the ideal value with varying speeds of the vehicles for three values of weight α and β. We observed that at lower speeds such as 60 and 70 km/h, the variation between α, $\beta = 0.5$ and α, $\beta = 0.75$ is not very high while further lowering their values results in significant variation. However, as the speed increases, the variation also increases significantly. The reason lies in updating frequency of *degree* and *betweenness utility*. As the speed increases, more recent values of centralities are required in order to utilize the social attributes because of the changes in network topology. This is evident from the fact that the efficiency of SUDS with α, $\beta = 0.75$ is 12.8% and 30.7% higher than α, $\beta = 0.5$ and α, $\beta = 0.25$, respectively, at a speed of 60 km/h. This difference further increases up to 28.9% and 55.02% for the values of α, $\beta = 0.5$ and α, $\beta = 0.25$, respectively, at a speed of 120 km/h.

In order to analyze the effectiveness of infrastructure support, we examined the performance of SUDS under hybrid and distributed models of VSNs. Figure 9b shows the delivery ratio of both models with varying vehicular density for speeds at 70, 90 and 110 km/h. It can be observed that the delivery ratio of the purely distributed model is significantly affected by varying vehicular density and speed, while it remains relatively stable in hybrid model. For example, the difference between delivery ratios of hybrid model at density of 70 V/km are 93.4%, 91.7% and 89.3%, while the delivery ratio of distributed model is 79.4%, 74.5% and 64% for speeds of 70, 90 and 110 km/h, respectively. As the density increases the gap in delivery ratio further increases for hybrid model with an increase in speed while in the hybrid model, the difference is reduced. For instance, the delivery ratio of the distributed model at 100 V/km is 89.5%, 85.3% and 75.3% while that of the hybrid model is 96.8%, 95.3% and 94.8%, for speeds of 70, 90 and 110 km/h. Figure 9c shows the comparison of hybrid and distributed models in terms of transmission delay. Here it is also evident that hybrid model achieves the goal with a lower delay than the distributed model. The reason for such behavior is the difficulty of social connections' utility in the purely distributed system at higher speeds, while in the hybrid model the support of RSUs overcome this shortcoming. Therefore, our observations indicate that for VSNs and other social utility-based vehicular networks, hybrid model is relatively more stable and scalable for the dissemination of EWMs.

6. CONCLUSIONS

We proposed a novel emergency warning messages dissemination scheme (SUDS) for Vehicular Social Networks. In SUDS, we employ social properties, such as centrality, friendships and interest groups in order to mitigate the problems like broadcast storm and hidden terminal. Moreover, to ensure connectivity and reliability throughout, we devised a dual-strategy-based mechanism by taking advantage of the hybrid architecture of VSNs. We divided the road section into three zones namely immediate zone, critical zone and social zone, based on the severity of the emergency. For each zone, we proposed algorithms for dissemination. Furthermore, to analyze the performance of SUDS, we conducted extensive experiments under a highway scenario with varying road length, speed and density of vehicles. The simulations demonstrated that SUDS outperforms state-of-the-art dissemination schemes in terms of the delivery ratio, transmission delay and total number of transmissions. We also evaluated and compared the performance of SUDS under hybrid and distributed network models.

As VSNs are still in developmental stages, they promise a lot of improvement and new features along with some challenges. For example, security, privacy and selfishness are some of the issues that are yet to be explored in VSNs. In future, we plan to work on a trust-based dissemination strategy for VSNs because a false-alarm can not only deceive users but can also create a lack of trust in the system which may cost precious lives. We will also explore issues like privacy and selfishness in VSNs in the future.

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